UNIVERSITI PUTRA MALAYSIA

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

FIRE PERFORMANCE AND PROPERTIES OF PARTICLEBOARDS MADE FROM KENAF (*Hibiscus cannabinus* L.) CORE TREATED WITH FIRE RETARDANTS

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August 2009

Chairman: Associate Professor Zaidon Ashaari, PhD

Faculty: Forestry

A study was undertaken to evaluate the fire performance and properties of particleboard made from kenaf core treated with fire retardants. The specific objectives involved firstly, to determine the optimum concentrations of phosphorous-based fire retardants (monoammonium phosphate [MAP]), diammonium phosphate [DAP] and mixture of guanylurea phosphate, boric acid and phosphoric acid [BP®] for the treatment of kenaf particles; secondly, to determine the buffering capacity and gelation time of mixture of particles with fire retardants; and thirdly, to evaluate the adverse fire performance of kenaf particleboard fabricated from pre treated particles and to assess the physical and mechanical properties of the treated particleboard. Kenaf core particles with size 1-2 mm were first soaked in hot fire retardant solutions for ten min with two concentrations (8% and 10%). Kenaf particles that had been soaked in 10% concentration of DAP, MAP and BP® took 14, 15 and 36 min to achieve the standard chemical loading respectively. Longer soaking times were recorded for kenaf particles soaked in the same fire retardant solutions at 8% concentration. The cold soaking times recorded were 21, 36 and 48 min to achieve the standard chemical loading. This shows that the kenaf core particles absorbed the chemicals faster in 10% than in 8% concentration of fire retardant solutions. For buffering capacity, the untreated kenaf core, DAP-treated kenaf core, MAP-treated kenaf core and BP®-treated kenaf core at 10% concentration needed 39.3, 136, 162

and 169 ml of NaOH to achieve pH 11 and smaller amounts of H_2SO_4 were used to achieve pH 3 i.e. 4.00, 7.75, 9.6 and 14 ml respectively. Similar results were recorded for kenaf core untreated and treated with 8% fire retardants. The kenaf core, DAP-treated kenaf core, MAP-treated kenaf core and BP®-treated kenaf core at 8% concentration needed 39.3, 176, 103 and 156 ml of NaOH to achieve pH 11 and the smaller amounts of H_2SO_4 used to achieve pH 3 were 4.00, 17.5, 11.25 and 9 ml respectively. DAP-treated kenaf was found to have a lower buffering capacity towards alkali compared to other fire retardants for both concentrations. As for gelation time, the average times taken for 8% MAP-mixed resin and 8% DAP-mixed resins to cure were 28 and 150 s respectively. The pH values of these resins were 5, 8 and 6 respectively. The average times taken for 10% MAP- mixed resin, DAP-mixed resin and BP®-mixed resin to cure were 20, 160 and 101 s, with the pH values of the mixtures being 4, 9 and 6 respectively. As for the control sample, the average curing time was 140 s and the pH was neutral. Particleboards with density 700 kg/m^3 from these treated kenaf core particles (10% concentration) were fabricated and their fire resistance, early burning and fire propagation performance were evaluated. Among the three phosphorous-based formulations, BP® showed the best performance in improving the insulation and integrity of kenaf particleboard. This was followed by MAP and DAP. BP®-treated board ignited least readily when compared with the rest of the boards. DAP and MAP were able to delay the maximum early heat release of the boards by about 15 to 16 min and 18 to 20 min respectively compared to BP® which was only able to delay the maximum early heat release by about 10 to 15 min after ignition. The heat release of the DAP and MAP-treated particleboards started 5 min after ignition, but the heat release of the BP®-treated boards started from the beginning of the test. It was shown that DAP-treated particleboards complied with the thickness swelling and water absorption requirements of the British-European standard. BP®-treated particleboards were found to have performance values better than the British-European standard requirement values for MOR and MOE. MAP-treated particleboards surpassed the standard requirement value for IB. All treated particleboards complied with the standard requirement of MOE except the DAP-treated particleboards. The untreated particleboards complied with all the standard requirements.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PRESTASI API DAN SIFAT PAPAN SERPAI DIPERBUAT DARI KENAF (*Hibiscus cannabinus* L.) CORE YANG DIRAWAT DENGAN PERENCAT API

Oleh

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Ogos 2009

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Sebuah kajian telah dijalankan untuk menilai prestasi api dan sifat papan serpat yang diperbuat dari kenaf core yang dirawat dengan perencat api. Objektif spesifik yang terlibat ialah, pertama, untuk menentukan kepekatan optimum perencat api berasaskan fosforus (monoammonium phosphate [MAP] , diammonium phosphate [DAP] dan campuran guanylurea fosfat, asid boric dan asid fosforik [BP®] untuk rawatan partikel kenaf; kedua, untuk menentukan 'buffering capacity' dan masa menjadi gel campuran partikel dengan perencat api; dan ketiga, untuk menilai prestasi api papan serpai kenaf yang difabrikasi dari partikel yang telah dirawat dan juga untuk mengkaji sifat fizikal dan mekanikal papan serpai yang telah dirawat. Partikel teras kenaf bersaiz 1-2 mm terlebih dahulu telah direndam dalam pekatan perencat api yang panas selama 10 minit pada dua kepekatan (8% dan 10%). Partikel teras kenaf yang direndam dalam DAP, MAP dan BP® pada kepekatan 10% mengambil masa 14, 15 dan 36 minit untuk mencapai bebanan bahan kimia piawai. Masa rendaman yang lebih panjang telah dicatat untuk partikel teras kenaf yang direndam dalam pekatan perencat api yang sama pada kepekatan 8%. Masa rendaman sejuk yang dicatat ialah 21, 36 dan 48 minit untuk mencapai bebanan bahan kimia piawai. Untuk 'buffering capacity', teras kenaf yang tidak dirawat, teras kenaf yang dirawat dengan DAP, teras kenaf yang dirawat dengan MAP dan kenaf

core yang dirawat dengan BP® pada kepekatan 10% memerlukan 39.3, 136, 162 dan 169 ml NaOH untuk mencapai pH 11 dan amaun H_2SO_4 yang lebih rendah digunakan untuk mencapai pH 3 iaitu 4.00, 7.75, 9.6 dan 14 ml. Keputusan yang sama telah dicatat untuk teras kenaf yang dirawat pada kepekatan 8%. Teras kenaf yang tidak dirawat, teras kenaf yang dirawat dengan DAP, teras kenaf yang dirawat dengan MAP dan kenaf core yang dirawat dengan BP® pada kepekatan 8% memerlukan 39.3, 176, 103 dan 156 ml NaOH untuk mencapai pH 11 dan amaun H_2SO_4 yang lebih rendah digunakan untuk mencapai pH 3 iaitu 4.00, 17.5, 11.25 and 9 ml. Kenaf yang dirawat dengan DAP didapati mempunyai 'buffering capacity' yang lebih rendah terhadap alkali berbanding perencat api lain untuk kedua-dua kepekatan. Untuk ujian masa menjadi gel, masa purata untuk resin yang dicampur 8% MAP, 8% DAP dan 8% BP® untuk mengeras adalah 28 dan 150 saat. Nilai pH resin ini adalah 5, 8 and 6. Masa purata untuk resin yang dicampur 10% MAP, 10% DAP untuK mengeras adalah 20, 160 and 101 s dengan nilai pH resin ini adalah 4, 9 dan 6. Masa pengerasan untuk sampel kawalan adalah 140 saat. Papan serpai dengan isipadu 700 kg/m^3 dari partikel yang telah dirawat ini (kepekatan 10%) telah difabrikasi dan prestasi ketahanan api, pembakaran awal dan penyebaran apinya telah diuji. Di antara ketiga-tiga formulasi berasaskan fosforus tersebut, BP® menunjukkan prestasi terbaik dalam meningkatkan insulasi dan integriti papan serpai kenaf. Ini diikuti dengan MAP dan DAP. Papan serpai yang dirawat dengan BP® didapati paling lambat terbakar berbanding papan serpai yang dirawat dengan perencat api yang lain. DAP dan MAP mampu untuk melambatkan penyebaran haba awal papan serpai selama 15 hingga 16 minit dan 18 hingga 20 minit berbanding BP® yang hanya mampu melambatkan penyebaran tersebut selama 10 hingga 15 minit sesudah penyalaan. Penyebaran haba papan yang dirawat dengan DAP dan MAP bermula 5 minit selepas penyalaan, tapi penyebaran haba oleh papan serpai yang dirawat dengan BP® adalah bermula dari awal ujian. Ia juga didapati bahawa papan serpai yang dirawat dengan DAP melepasi keperluan piawai penyerapan air dan pengembangan ketebalan mengikut piawaian British-European. Papan serpai yang dirawat dengan BP® didapati mempunyai nilai prestasi yang lebih baik daripada nilai piawaian British-European untuk ujian MOR dan MOE. Papan serpai yang dirawat dengan MAP melepasi nilai piawaian untuk IB. Semua papan serpai yang dirawat melepasi piawaian untuk MOE kecuali papan yang dirawat dengan bahan perencat api, DAP.

APPROVAL

I certify that a Thesis Examination Committee has met on **26th August 2009** to conduct the final examination of **Izran bin Kamal** on his thesis entitled "**Fire Performance and Properties of Particleboard made from kenaf core (*Hibiscus cannabinus* L.) Treated with fire retardants**" in accordance with Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the **Master of Science Wood Science and Technology.**

Members of the Thesis Examination Committee were as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date: 16 November 2009

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledge. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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IZRAN BIN KAMAL

Date: 16 September 2009

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LIST OF ABBREVIATIONS

g/cm^3	gram per centimetre cube
ASTM	American Standard Testing Method
ºC	Degree Celsius
MDF	Medium Density Fibreboard
h	hour
F	Fahrenheit
FAO	Food and Agricultural Organisation
USDA	United States Department of Agriculture
lb	Pound
µm	Micrometer
kg/m^3	Kilogram per meter cube
mm	Millimetre
CO_2	Carbon dioxide
MARDI	Malaysian Agricultural Research and Development Institute
R&D	Research And Development
ha	Hectare
s	Second
N	Normality
ml	Millilitre
w/w	Weight per weight
g	Gram
MC	Moisture content

OD	Oven dry
psi	Pounds per square inch
RH	Relative Humidity
N/mm^2	Newton per millimetre square
G	G-Force
H_2SO_4	Sulphuric acid
NaOH	Natrium hydroxide
NH_4Cl	Sodium chloride
m	Metre

CHAPTER 1

INTRODUCTION

1.1 General Background

Kenaf (*Hibiscus cannabinus L.)* is a fibrous plant that originally came from Western Sudan, Africa and is closely related to okra and cotton (*Gossypium hirsutum L.*) (Mohamad Jani *et al.,* 2004 and Anon, 1999). The term kenaf probably originated with the Persians who used this word to describe the plant *Hibiscus cannabinus L*, which they used for pulp and fibre (Anon, 1999). Kenaf had been introduced to Malaysia in the early 70s but it was only highlighted in the late 90s as an alternative crop for rubberwood (Paridah et al., 2008). Kenaf also is a very popular fibrous crop nowadays due to its fast growth (Anon, 2005). Kenaf is grown commercially for fibre production in many areas of the world, with the largest producer being the People's Republic of China. In the United States, kenaf production is located in Texas, Louisiana, Mississippi, and California. Kenaf is used in the manufacture of various paper and pulp products, poultry litter, potting soil amendments, chemical- and oil-spill absorbents, animal and horse bedding, and packing materials. Potential uses include the manufacturing of filters, particleboards and insulation boards. Kenaf leaves, which contain 20–30% crude protein, may also have potential as a livestock feed source (Anon, 2009g). Other uses of kenaf as stated by Dishon (2003) are:

- The leaves are high in protein and can be harvested and pelletized for high fibre and high protein feed.
- The seeds contain a non-allergenic, odourless oil for cooking or cosmetics.
- The fibres in the stalk can be used for paper, particleboard, studs and barbecue chips. (They emit no sulphur dioxide gas when burned, thus no acid rainfall or pollutant to the air)
- The fibre is biodegradable and environmentally friendly. It has been researched that kenaf produces photosynthetically as much as 20 times the amount of O_2 of yellow pine on the same amount of land.

  It is an agricultural crop annually renewable with a minimum amount of farming.

In Malaysia, rubberwood is well known for MDF and particleboard. Due to the demand of the wood which is higher than the supply, the price of rubberwood has increased drastically. The supply of rubberwood has kept decreasing and failed to meet the demand as more rubber plantations are converted to oil palm plantations and housing areas. Kenaf has been identified to be as one of the potential raw materials, due to its fast-growing characteristic, which can help to meet the raw material demand (Paridah *et al.*, 2007). Kenaf stalk, which comprises a woody inner core and fibrous outer bast, is a rich source of fibre. The core of kenaf is light and porous, having a bulk density of 0.10 - 0.20 g/cm^3. It can be crushed into lightweight particles. The cellulose and lignin contents of kenaf core are similar to those of wood, but the hemicellulose content is much higher. The cellulose and lignin contents of kenaf core are 31 - 33% and 23% - 27% respectively (Alireza *et al.,*2003). At present, about 400 farmers are involved in planting kenaf in nearly 1,400 hectares of land, mainly in Kedah, Kelantan, Perlis and Terengganu (Anon, 2009). In Kelantan, there are 27 farmers involved in kenaf plantation in Bachok and Pasir Puteh. These states (Kedah, Kelantan, Perlis and Terengganu) are chosen for planting kenaf because the government wants to create more work opportunities for the residents (Anon, 2009). Kenaf produces 3 - 6 tonnes of dry fibres per hectare, which is three or five times more biomass compared with most forest species. Based on this amount, and the possibility of planting twice a year, kenaf could be a viable alternative source material for the manufacture of MDF, particleboard and pulp and paper (Paridah *et al.,* 2009). The proportion ratio of kenaf bast to core fibre is 40:60, but, the bast fibre is often used as raw material to produce particleboard due to the length and straightness of the fibres compared with the core (Paridah *et al.,* 2009). However, it is a waste if the core is not as fully utilized as the bast.

Particleboards from kenaf can be used for partition, panelling, furniture components and flooring. Many studies have been conducted around the world confirming that kenaf-based composites possess acceptable physical and mechanical properties. It has been reported by Paridah *et al.* (2004; 2009) that kenaf core-based particle boards were able to give better MOR, MOE, internal bond, thickness swelling and water absorption performances than rubberwood-based particleboards. Muehl *et al.* (1999) studied the strength of kenaf-based particleboard under the influences of different amounts of resin and wax used. They found that the mechanical performance of kenaf-based particleboards could be improved with the reduction of wax and increase of resin loading. However, the increase of resin loading caused the particleboards to have poor water absorption and thickness swelling. Kenaf also has been used as a raw material to produce kenaf-based plastic polymer composites with superb strength performances. Ahmad Zharif (2008), conducted seven different mechanical tests on kenaf-based polymer composite such as fractural modulus, fractural strength, impact strength, tensile strength, yield strength, elongation at break and tensile modulus. He found that the kenaf-based polymer composite performed well in all the tests and surpassed the ASTM standard requirements. The results were in a good agreement with those of Jalaludin (2001). With the evidence shown above, kenaf without doubt can be used in various ways in composite industries.

According to Australian Wood Panel Association Incorporated (2008), particleboards are naturally combustible and the combustibility varies with the density and the type of board used. According to Abdul Rashid (1982), chipboards are combustible and have similar fire propagation performance as some timbers. Due to this, Uniform Building By-Laws allow particleboards to be used as structural materials and also non-structural material in buildings of up to four storeys high.

This project was carried out to determine the effectiveness of selected fire retardants commercially available in the market, namely diammonium phosphate (DAP), monoammonium phosphate (MAP) and BP® (mixture of 27 - 33 % boric acid, 67 - 73 % guanylurea phosphate and 0 - 4.2 % phosphoric acid) in particleboard made from kenaf core. These phosphorous-based fire retardants were impregnated into the particleboard through the modified hot and cold bath process. Based on a previous research (Syed Noridzzuan, 2000), it has been proven that adequate and proper treatment of fire retardant chemicals can improve fire performance of wood particleboard. Apart from that, the project was intended to expand the utilisation of kenaf core fibres which are often less popular compared with the bast fibres in particleboard production..

1.2 Problem Statement and Justification of the Study

Rapid development of buildings and infrastructures has created a high demand for wood panel products. Particleboard is readily available in the market; but, unfortunately its usage is limited, especially for high rise buildings due to its combustible properties (Anon, 2009h). According to the standard specified by BS 476 Part 1, particleboard is classified as a combustible material (Aznita, 1999). It is proved that the combustible properties of the particleboard can be improved by impregnating fire retardant chemicals into the board. Mohammad Jani (2008) produced fire retardant-treated kenaf core particleboard by adding the chemical (mixture of guanylurea phosphate, boric acid and phosphoric acid) during the mixing stage. The board increased in fire performance, but slightly decreased in mechanical and physical properties.